A Phenomenon connected with the Discharge of Electricity from Pointed Conductors.

By H. T. Barnes, Macdonald Professor of Physics, and A. N. Shaw, Demonstrator of Physics, McGill University, Montreal; with a Note by John Zeleny, Professor of Physics, University of Minnesota.

The discharge of electricity from pointed conductors has been the subject of many important investigations, notably by J. J. Thomson, Chattock, Warburg, Zeleny, and others. The effect of moisture on the discharge has recently been studied in detail by Zeleny,[*] who was the first to observe the formation of a coloured deposit on steel needle points when observed under a microscope. He describes this deposit as having a reddish-brown colour, resembling ordinary rust, which is attached to the point in irregular pieces which extend outward some little distance, and finds it produced even in fairly dry air. A marked difference in the volume of the deposit was observed, depending on the direction of the discharge to the point. As anode the amount was much in excess of that produced when the point was made the cathode. As Prof. Zeleny passes over this phenomenon with but a brief mention for the steel points he used, we considered it of interest to study this deposit more in detail, using pointed conductors of various metals, and to observe what effect the presence of the deposit had on the discharge. It appeared to us probable that the deposit was connected with the presence of moisture in the air surrounding the point, and that it could be eliminated altogether by having absolutely dry air. We have found this to be the case, and in consequence one of the disturbing factors connected with point discharge may be eliminated only by working with air from which every trace of moisture has been removed.

Most metals react easily with oxygen in the presence of moisture, but especially when made the anode in an electric circuit. It has been shown by one of us, working with Mr. G. W. Shearer,[†] that the metals aluminium, magnesium, and zinc, form, as the first stage of their oxidation, hydrogen peroxide, when immersed in water containing dissolved air or oxygen. The amount of peroxide formed was observed to be considerably increased when the metal was made an anode. Other metals, such as iron, appear at once

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* 'Phys. Rev.,' vol. 25, p. 305, 1907; 'Phys. Rev.,' vol. 26, p. 448, 1908.
† 'Journ. Phys. Chem.,' vol. 12, p. 155, 1908; vol. 12, p. 468, 1908.

to decompose any peroxide produced as fast as it is formed. It seems highly probable that the first three metals form over their surface a protective film which, in the case of aluminium,* is exceedingly resistant. The non-formation of this surface film allows free action between the hydrogen peroxide produced and the metal, resulting in the decomposition of the former and further oxidation of the latter. The formation of the surface film on aluminium has been frequently studied, especially in connection with the asymmetric conductivity of that metal. The readiness with which the surface film may be broken down by the current, when travelling from the metal as cathode, indicates, we think, the incompleteness of the oxidation producing the film.

When a considerable amount of clean and pure aluminium foil is immersed in water containing dissolved air, the amount of which is kept up by bubbling or agitation, the amount of peroxide is considerably increased. The passage of a current with the foil as anode and a small wire cathode still further augments the yield. This was also observed in the case of zinc, and to a less extent for magnesium. An attempt at quantitative estimations of the amount of peroxide produced was made by colorimetric tests, using starch and potassium iodide, and comparing with a very dilute solution of standard hydrogen peroxide. With aluminium and zinc it was not possible to increase the yield by more than 1 part in 50,000, while for magnesium this was found much smaller, *i.e.* 1 part in about 600,000.

The photographic effect of metals, which was thought at one time to be due to the emission of an emanation or of rays, has recently been shown by S. Saeland† to be due probably to the formation on a clean metal surface of hydrogen peroxide produced by reaction with the moisture in the air. The metals which were found to be most active were magnesium, aluminium, and zinc, which are the three we have found to yield measurable quantities of peroxide in water with dissolved oxygen. Saeland produced the effects of the so-called metal rays by small traces of peroxide, and no trace of photographic action was observed from a clean metal surface in perfectly dry air or in hydrogen. In the light of all these results we considered it highly probable that the deposit on the steel points obtained by Zeleny was due to moisture in the air surrounding the electrode which, under the influence of the electrified gas, was condensed around the negative oxygen ions and swept into the metal anode point. Townsend has shown‡ that an electrified gas has the power of condensing moisture, even in an unsaturated

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* 'Am. Electrochem. Soc. Trans.,' vol. 13, p. 169, 1908.
† 'Ann. d. Phys.,' vol. 26, p. 899, 1908.
‡ 'Camb. Phil. Soc. Proc.,' vol. 9, p. 249, 1897.

atmosphere.   How minute a trace of water vapour in the air can be condensed on the negative ions has been indicated in some recent experiments of Prof. Townsend.*   The production of minute droplets in a gas containing only a small amount of moisture would probably not be observable by transmitted light unless viewed through a great thickness of gas.   Such a tenuous cloud is probably the cause of the haze often observed in the atmosphere† at low values of the relative humidity.

Our experiments appear to show that even a minute trace of water vapour is condensed around, and thus carried to the metal by the negative oxygen ions which cause the formation of the deposit, and that these ions alone are not able to cause the oxidation of the point even under a powerful electric field.

Before describing the apparatus used in this work, which was essentially the same as that employed by Zeleny, we wish to describe and, as far as possible, classify the various deposits observed on the different metal points.

In every case the deposit was examined under the microscope after the point was removed from the apparatus.   No observations could be conveniently made while the discharge was passing.

Appearance of the Deposit.

It was found, at the outset, that a low-power microscope failed to reveal the character of the deposit, and merely indicated the presence of some foreign material at the point.   This, to the unaided eye, was in the majority of cases absolutely invisible.   A microscope of high power was, therefore, used to study the nature of the growths which we have classified under the different heads as follows :—

I. Granular Formation.
II. Tubular or Icicle Formation.
III. Smooth Formation.
IV. Thin-film Formation.

The four types are all probably connected with each other, but in appearance they are quite distinct.

I. *The Granular Formation.*

This formation appears in irregular growths which, under certain conditions, will extend to a distance of about a tenth of a millimetre from the surface of the point; but is usually of a far smaller order.   The shape

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* 'Roy. Soc. Proc.,' A, vol. 81, p. 464, 1908.
† Frank W. Proctor, 'Monthly Weather Review,' vol. 35, p. 22, 1907.

of these growths (see figs. 1, 2, and 3) is very similar to that of ordinary rust, as seen under the same microscope. They are composed of minute particles resembling powdered crystals; it is for this reason that we have called the deposit "granular." Thin portions show a translucence usually colourless, the thicker portions are almost opaque and vary from dark reddish brown (for steel) to grey black (in the case of copper).
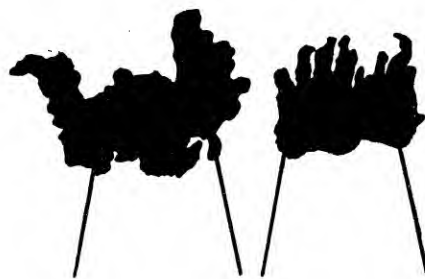
FIG. 1.—Steel Anode Points.   FIG. 2.—Aluminium Anode Points.

This form of deposit is the most prevalent one, and may be considered as the final stage. It probably passes through types (II) and (III) before becoming granular. In fig. 4 is shown the amount of deposit on the same point discharging negatively.

FIG. 3.—Detached Granular Deposit.   FIG. 4.—Steel Cathode Point.

II. *The Tubular or Icicle Formation.*

These formations are most interesting in appearance (see figs. 5 and 6). Varying from yellow to colourless they have almost the exact appearance of
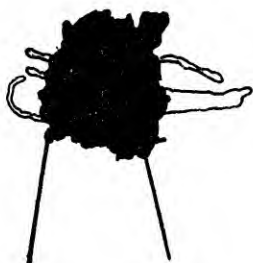
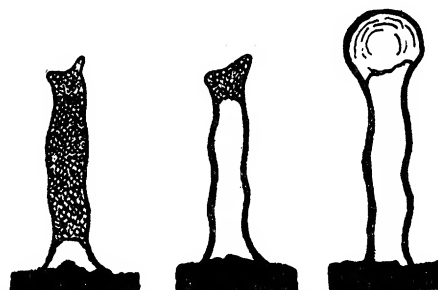FIG. 5.—Anode Deposit with   FIG. 6.—Tubular Growth showing Water Core
Five Tubular Growths.   at Different Levels.

the common icicle.   A similar formation can be obtained by dipping aluminium into HNO_3 and then into Hg.   It was observed on one occasion that a piece of freshly scraped nickel developed a few very small icicle formations without electric discharge.

The icicles are to be seen in three forms :—

(*a*) A growing form with liquid core.
(*b*) A permanent form with liquid core.
(*c*) A permanent form with hollow core.

All three forms consist of a thin tube whose sides are apparently composed of the more opaque granular formations.   In (*a*) the tube is filled with a very mobile fluid which rises and falls rapidly with any change in the immediately surrounding humidity.   If there is sufficient change the fluid will rise beyond the extremity of the icicle, and form a large bubble which may burst.   The film of this bubble is very thin and will sometimes show very pretty coloured interference effects.   In receding back into the tube, under the influence of dry air, the fluid leaves the icicle extended and further developed.   In this condition the granular formation of the walls of the icicle becomes visible, and a large part of the transparency is lost ; the tube appears to dry up, and the outlines of each granule stand out.   If the fluid rises again it appears to soak into the sides, and the whole once more becomes translucent.   These different phases are illustrated in fig. 6.

(*b*) The permanent form with liquid core :—The mobile fluid in the bubble often becomes thick, and eventually viscous, before receding into the core of the icicle.   In this case the whole hardens into a permanent shape of a dark but even colour, in which case the granular formation cannot be distinguished.

(*c*) The permanent form with hollow core :—This is merely the dry tube mentioned above in the special case when the fluid has receded first and then hardened, leaving behind a permanent granular icicle.

III. *The Smooth Formation.*

This formation consists of the hardened fluid already described, existing by itself in flat spheroidal drops (see fig. 7).   There has been no building up of granular tubes previous to the hardening of the surface.   In colour this deposit is usually a dark yellow or brown.

IV. *The Thin-film Formation.*

The thickness of this formation cannot be observed ; it is perfectly transparent, and can only be seen as a definite band of interference colours across

the surface of the untarnished metal, just below the point (see fig. 8).   These zones of colouring are, however, always bordered on the side nearest the point by a very narrow black band, which seems to either merge into the region of the granular deposit, if there is any, or stop suddenly if there is

Fig. 7.—Smooth Formation.   Fig. 8.—Thin Film Formation.

none, and leave the point itself quite clean.   The black band, like the film, has no appreciable thickness.   It is, however, often visible to the naked eye, and under long treatment will develop into a smooth black tarnish.

Production of the Deposit.

A. *The Apparatus used.*—To permit the use of dry air, oxygen, etc., the point and plate were placed in a closed brass cylinder.   The cylinder used is shown in fig. 9.
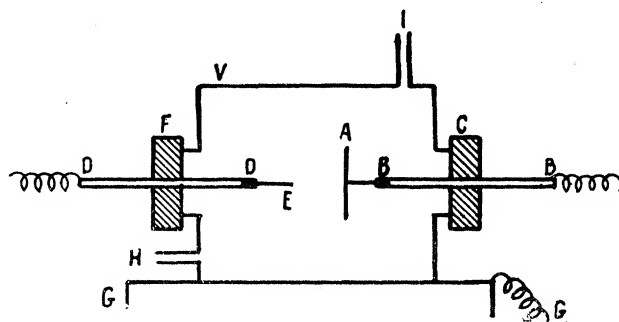
Fig. 9.—Discharge Chamber.

The figure is a vertical section.   The brass cylindrical vessel V is 13 cm. high and 15 cm. in diameter.   It is kept connected to earth in order to prevent the apparatus becoming charged.   The plate A is a flat smooth brass disc, 6 cm. in diameter, which fits into a metal holder BB, connected to one terminal of the electric machine.   Besides the plate A, another plate, 1·8 cm. in diameter, two rings, and several rounded and plane wire ends were tried, but in most cases the plate A was found to be the best.   The holder BB is insulated from the vessel by means of a hard rubber plug C, into which it fits tightly.   In a similar manner a metal rod DD, connected to the other

2 A 2

terminal of the electric machine, holds the point E and fits into the insulating plug F. The rods DD and BB are graduated, and can be moved to adjust the distance between the point and the plate. The vessel V is made comparatively air-tight with the detached bottom G by means of tap-grease or vaseline. There was a small removable window in the side of the vessel, which is not shown in the figure. H and I are tubes, by means of which dry air, oxygen, etc., can be introduced and passed through the apparatus.

To generate the current a Wimshurst machine was used. Since the humidity of the summer weather, during which these experiments were performed, made it impossible for this open type of machine to be operated under ordinary conditions, it was mounted over a large electric heater, which thoroughly dried both it and the surrounding air. The machine could be turned rapidly by means of a small motor. This enabled us to get a potential difference between point and plate when 2 cm. apart of over 20,000 volts.

The air or oxygen was dried by passing first through a calcium chloride tower, then through sulphuric acid, and finally through cotton wool. In addition, a dish of H_2SO_4 was required within the vessel V, when perfect dryness was desired.

The points used were made of various metals (mentioned elsewhere) by filing as finely as possible with a revolving machine file, except in the case of steel, when ordinary needles of sizes 10, 8, and 5 were used.
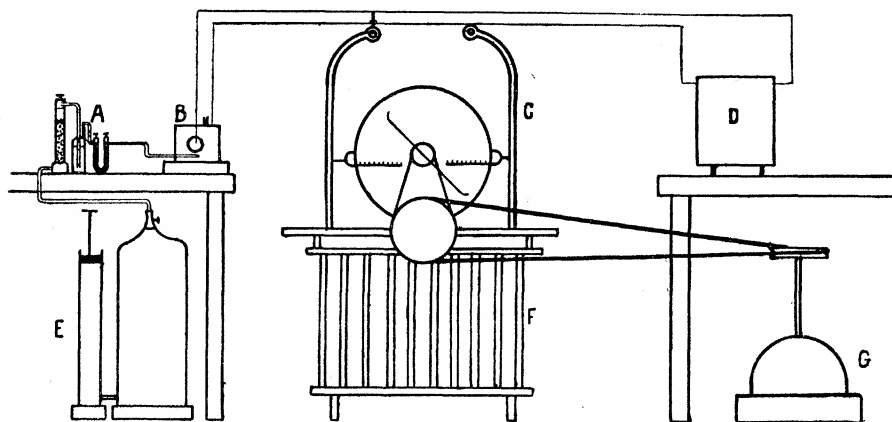

FIG. 10.—Apparatus and Connections.

Fig. 10 represents a diagram of the general connections:—

A is the drying apparatus.

B is the vessel V of fig. 9.

C is the Wimshurst machine.

D is a Kelvin electrostatic voltmeter measuring up to 20,000 volts.

E is the air tank and pump—or else a gasometer for oxygen.

F is the electric heater.

G is the motor.

For the experiments using air under pressure, a specially air-tight cylinder and a mercury gauge were substituted for the vessel V. In this case the cylinder is 20·5 cm. long and 11·5 cm. in diameter. The plate used is the same as A, which is the plate used before. The point and plate are supported and insulated in a similar manner to the former apparatus, but in this case the metal holders have to be waxed where they fit the insulating plugs, otherwise the vessel would leak under pressure. The distance between the point and plane was adjusted by means of a metal sleeve.

B. *Methods and Conditions*:—Metals used.—The deposit can be produced on various metals. The following list will give an idea of the relative amounts obtained on the more common metals when discharging as anode :—

(1) Aluminium, (2) zinc, (3) steel, (4) cadmium—gave the largest deposits in order.

(5) Tin, (6) magnesium, (7) silver, (8) brass, (9) copper—gave medium to very small deposits.

(10) Platinum—gave fine tarnish after 40 minutes' treatment.

(11) Lead, (12) nickel, (13) palladium—probably no deposit, but doubtful.

(14) Gold—no deposit.

In the case of the first five metals of the above list it was found that the points always gave a much larger quantity of deposit when they were positive electrodes than when negative. The quantities formed on the remaining metals were so small that, with one exception, it was impossible to form a comparison. The exception was silver, where the granular deposit appeared appreciably only when the electrode was discharging negatively, and the thin-film deposit only when discharging positively. The deposit formed on any of the negative electrodes was always more evenly distributed over the point; it appeared, also, to be in a more finely divided state. It was noticed that the potential difference for a given distance was always less (from 5 to 40 per cent., according to point) for negative discharge than for positive. The shape of the two glows also differed considerably, and the positive was brighter at the surface of the metal.

Effect of Distance and Potential.—Throughout the work the supply of current was kept about the same, hence the potentials always varied with the distance used, and it is therefore necessary to discuss the two together. Their effect on the amount of deposit is a considerable one; the table below gives the average results of several observations for each distance.

	Distance.	Average potentials.	Amount of deposit.
	cm.	volts.	
Using steel points	0·1	200	Small
	0·2	2,000	,,
	0·5	3,000	,,
	1·5	8,800	Medium
	2·0	10,300	Very large
	3·0	?	Medium
	5·0	18,000	Small
Using aluminium points.................	0·5	4,800	,,
	1·0	6,400	,,
	2·0	11,000	Very large
	2·5	13,000	Large
	3·0	16,000	Medium

(The first three results were affected by sparking, which always renders the reading of the potential difficult, owing to the erratic jumping of the voltmeter. It also blows away the deposit from the point.)

Fresh points were used each time, for we found that the number of times a needle has been used has an important effect on the amount of deposit produced.

It will be seen from the table that for both aluminium and steel the distance for maximum deposit is 2 cm. This distance also gave the best deposit for zinc.

Classification of Effects.—In regard to these various influences on the production of deposits, we can classify them as having effects of the "First" or "Second Order." The sign of the current and the distance have effects of the first order, but time, within certain limits given below, has an effect of the second order.

The shape of the needle has a close connection with the potential. We found that very sharp points considerably increased the deposit, and blunt points developed only very small growths; but for various degrees of sharpness within these extremes there was not very much variation. The effect must, however, be classed as one of the first order.

The time of discharge is not, as might be supposed, a very important factor. For the first 10 minutes when the deposit is commencing to form, the amount increases perceptibly with the time, and up to this period time may be called a factor of the first order; but after the first 15 minutes the deposit grows so very slowly that for all periods of increase less than half an hour one may say that time is a factor of the second order. This statement refers only to cases when the ordinary air is used.

The number of times a needle has been used has an effect on the amount

of deposit which is often of the first order. If a needle has been used very often, the deposit is much slower in growth, and consequently in a given time we get less deposit than with a new needle; but, on the other hand, there seems to be an increased tendency to grow, because with points that have been frequently used we get the deposit continuing to form in the open air after the discharge has ceased. This apparently contradictory condition may be explained as follows :—Upon close observation of many points, it was found that the electric discharge had a very strong disintegrating, or we might say " deforming," effect on sharp points (see fig. 11). There is a con-
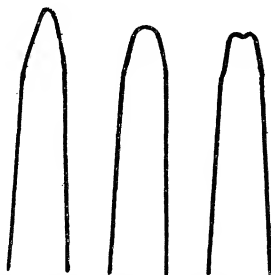

Fig. 11.—Magnified Needle Points before and after a Short and Long Discharge.

siderable blunting of the point, and, in some cases, a small crater is actually produced at the extremity. This can be observed in metals not producing deposits, as gold. We can therefore deduce—(1) that the deposit is actually decreased because the point is blunted, but (2) that the real tendency of continual usage is to make a given part of a surface which remains unaltered in shape *more* capable of producing deposit instead of less, as the observation at first sight suggested. We should really expect this to be the case, because another action of the current is to slightly roughen the surface, hence there is more surface exposed and we should have more deposit. In all these cases of continued usage the needle has, of course, been repeatedly cleaned.

Long enough usage of almost any shape of discharging terminal will ultimately tarnish the surface. Wire ends, sparking points of induction coils, and even the brass plates, all exhibit a considerable tarnish of the same nature as our deposit, provided the time of actual use can be measured in hours and days.

The question of the influence of the amount of moisture in the air is the most important determination of all.

So far the results were obtained by using the ordinary air of the laboratory. When the discharge was performed through air saturated with steam, we found that the amount of deposit was greatly augmented. The potential was, of course, greatly diminished for any given distance. It was also noticed that

the damp days were the most favourable for the production of large forma-
tions, especially of the icicle variety.

Using different degrees of dry air, we found that the amount of deposit
varied accordingly ; and, finally, if extreme precautions were taken for the
use of as dry air as possible, there is complete absence of deposit. In order
to obtain this dryness it was necessary to place a large dish of H_2SO_4 in the
apparatus, and to pass dry air through the vessel for at least 25 minutes
previous to discharging. This condition holds also for pure dry oxygen,
which is a much more powerful deposit producer than air. The use of
calcium chloride bulbs is not sufficient alone.

Decrease of humidity perceptibly decreases the deposit, but when we
approach absolute dryness there is a sudden jump from a considerable
amount of deposit to no deposit. It was found that we could repeatedly
eliminate the deposit in perfectly dry air or oxygen, but if the least possible
trace of moisture was introduced through the exit tube I by a very slight puff
of damp air at the beginning of the discharge without stopping the flow of
dry air, there was obtained an amount of deposit which was, in every case,
at least half of the maximum amount obtainable with steam. This result
shows that moisture must act as a catalytic agent in the production of these
formations, and the fact that the addition of a minute trace of moisture to
dry air raises the amount of deposit from zero to between 50 and 80 per cent.
of its maximum value suggests that although aqueous vapour is necessary to
start the formation, it is not necessary for the continuation of its growth when
once started, but if present it will certainly accelerate the growth by forming
fresh nuclei of action and thus extend the surface attacked.

Carbon dioxide does not apparently have any influence on the formation
of deposit. It was found that there was no difference between using
perfectly dry air containing CO_2 and perfectly dry pure oxygen.

The use of moist oxygen gave the largest deposits obtained for every
metal. The " moist " oxygen or " moist " air was obtained by allowing the
gas to bubble through clean water before entering the apparatus. It was
found that almost dry oxygen gave a larger deposit than air under ordinary
conditions. Moist oxygen increased the amount over that obtained with
moist air by about 50 per cent.

By first allowing a spark discharge for a few minutes and then inserting
the point, the presence of an appreciable amount of ozone was insured.
This had the effect of slightly diminishing the deposit. We do not, however
consider this as a proof that ozone is a deterrent in the formation of deposit
because in order to insure the non-escape of ozone it was necessary to close
the apparatus and thus lessen the amount of available moisture and oxygen.

It was found that a faint glow was the most suitable kind of discharge. If sparks crossed, the deposit was largely blown away. If a smaller brass plate or if rings were used for the opposite electrode, the discharging surface was lessened and the deposit decreased.

It was found that the mechanical circulation of new air or oxygen around the point greatly increased the deposit. The air was blown on to the point with different velocities. It was evident that the faster the motion of the air the greater the deposit; this fact held till the draught of air was strong enough to displace particles clinging to the point. In these experiments time was not of the second order in effect until the growth had continued for at least an hour. The best results we always obtained by arranging that the current of air was at right angles to the electric current.

In regard to the liquid core of icicle formations, we found that there was an equilibrium point between the quantity of fluid in the tube and the immediately surrounding air. If fresh supplies of air were rapidly brought into contact with the icicle while it was being observed under the microscope, the fluid rose in the tube; if moist air was used it rose and expanded into the large bubble described before. If dry air was directed on to the formation, the fluid receded and left behind the dry tube extended and enlarged. The phenomenon may be one of condensation and evaporation through the thin surface film.

By keeping moist air blowing very strongly on a platinum point while discharging for more than forty minutes, we were able to obtain a faint black tarnish, showing that even this comparatively inert metal is influenced by the electric discharge.

We made a large number of observations on the effect of pressure, but were unable to obtain very definite results.

At first sight these results appeared more contradictory than they really were. An examination of our observations shows that the following conclusions may be drawn :—

1. With new and consequently very sharp points, pressure increases the deposit.

2. With points that are not new and which have, consequently, their surfaces affected and their points blunted, increase of pressure decreases the deposit.

3. For ranges of pressure less than one atmosphere, the effect of change of pressure is of the second order and may act in either direction according to the condition of the point.

It was found that the smooth formation could generally be produced by placing a point coated with icicle formations in very moist air, or better, in

moist oxygen, and discharging at a shorter distance than usual. The icicles are apparently broken down into the granular formation, and the fluid adheres in spheroidal drops. These may again grow icicles.

Points coated with tap-grease yielded a small but very compact deposit. The insulating grease is evidently easily pierced.

Conclusions.

With the possible exception of platinum, in which case the formation may be platinum black, we think it safe to assume that the deposits are the oxides of the metals. This is supported by the fact that the growth is much greater when the point is positive than when negative. In regard to this circumstance, Prof. Zeleny says, in his paper, the reason why the oxide forms so much more readily during the positive discharge than it does during the negative may be that in this case negative ions of oxygen are carried from the surrounding air to the metal surface, and forming as they do the negative parts of the iron oxide molecules, they unite more readily with the iron than do the positive ions which are carried to the metal surface during the negative discharge.

Since it seems certain, from our experiments, that moisture is essential to the production of the deposits, it appears probable that in comparatively dry air the negative ions possess greater aptitude for collecting water vapour than do positive ions, just as in the case of a supersaturated atmosphere.

The appearance of the icicle or tubular deposit, which appears to be the beginning of the more permanent deposit on the point, looks as though it formed around a minute droplet of water, probably hydrogen peroxide. Each droplet is probably formed by the coalescing of the moisture condensed around several oxygen ions. As soon as this wets the metal surface, a ring of oxide is formed and appears to be drawn by surface tension, in a thin film, around the drop. As the film thickens it builds up from the base a hard compact tube, leaving the surface film stretched across the end. This film separates the liquid from its vapour and appears to permit the passage of the vapour. Hence in a dry atmosphere the liquid rapidly evaporates and leaves the tube hard and compact; in an atmosphere containing an appreciable amount of water vapour it remains in equilibrium ; while in a moist atmosphere the vapour is condensed through the film and the volume of liquid increased. Thus, as we have already described, when a tube is blown upon under the microscope with very moist air, the liquid appears to rise and swell out the end in the form of a bubble that may burst the film coating. When dry air is used to blow over the tube, the liquid appears to recede into the bone-like tube and disappear altogether.

The air in our laboratory is fairly moist in summer, with a humidity ranging from 60 to 90 per cent., which was the case when these measurements were made.   Hence, it was fairly easy to examine the rising and falling of the liquid core of the tubes under the microscope.   In winter, however, the humidity of our heated laboratory is low, ranging from 3 to 20 per cent., depending on the outside air temperature.*   Hence, at this time, any tubular forms that are produced in our apparatus with added moisture dry up before they can be removed to the microscope, only the dried-up hollow tube being observed.   If the droplet is increased when the sides have hardened we get an extension of the surface which slowly hardens after the manner of the natural water icicle.   Hence, tubes will grow by themselves on points removed from the discharging chamber if the atmosphere is very damp.

If the droplet does not grow, the hardening of the surface produces the smooth formation.   In regard to the order of development of these different deposits, we can regard the tubes or icicles and smooth formations as first produced.   The mechanical agitation of the air by the discharge will break most of the more delicate tubes immediately they are formed into the common and irregular granular deposit.

How far oxygen becomes occluded in the metal under electric pressure is uncertain, but it looks as though it might be in considerable quantities, and thus accelerate the growth of deposits after the discharge ceases.   The influence of moisture is very marked on the potential required to start a spark, as observed by J. J. Thomson, who describes a dry gas as being in an unstable state as far as many of its electrical properties are concerned.   On the application of a potential greater than is required to start the spark, the "lag" in a perfectly dry gas is very much greater than in one containing only a trace of moisture.   Hence the moisture acts as a kind of lubricant, either as a surface effect or in hastening the ionisation of the medium.

In conclusion, we add a note kindly supplied by Prof. Zeleny, to whom we submitted the manuscript.   The work is closely connected with the valuable study Prof. Zeleny has been making of Point Discharge, and we are especially gratified to be allowed to include his views here.

Note by JOHN ZELENY, Professor of Physics, University of Minnesota, Minneapolis.

The fact that the presence of water is always necessary for the formation of oxides has been **explained** by supposing that the chemical union can take

* Compare "Deficient Humidity of the Atmosphere," by T. A. Starkey and H. T. Barnes, 'Roy. Soc. Can. Trans.,' (2), vol. 12, p. 203, 1906.

place only in the presence of an electrolyte. The contact of the two elements with the water introduces ions of both into the liquid, where they unite to form the oxide. The results of Prof. Barnes and Mr. Shaw show that water is likewise essential to the formation of these deposits (evidently oxides) on discharging points. The difference in this case is that the oxygen comes to the metal in the ionic state, and since no union takes place when dry gas is used, we may conclude that both the oxygen and the metal must be in the form of ions before the two can unite chemically.

It is very probable, as the authors assume, that most of the water is carried to the positive points by the ions themselves. In measuring the velocities of the ions which are produced by Röntgen rays, I found that while the values obtained for the positive ions in air and oxygen were practically the same whether the gases were dry or moist, the velocities of the negative ions were considerably smaller when the gases were moist. This indicates that the negative ions become larger in the moist gases by attracting to themselves one or more molecules of water. A simple calculation shows that the accumulation of this water on the point is sufficient to account for the observed drops of liquid.

The existence of drops of liquid on the discharge point indicates that the average temperature there is not as high as the luminosity present in the adjacent gas might lead us to expect. An attempt was made to determine the rise in temperature of a point during discharge by using a compound discharge point made of two sharply-pointed wires of dissimilar metals held in contact at an acute angle at their very tips. The wires were included in a galvanometer circuit so that the compound point formed one of the junctions of a thermo-electric circuit, which was grounded near the point to prevent the discharge current from affecting the galvanometer. The discharge from the point was induced by a charged plate placed opposite to it. The observed rise in temperature was $10°$ C. for a discharge current of about 10^{-5} ampere. The actual rise in temperature at the discharging surface itself must be considerably greater than that observed, for the heat has to be conducted from the discharging surface to the surface of contact of the two metals, and the loss to the larger metal parts back of the point must be a large one.